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FREQUENCY STABILITY STANDARDS
FOR TELEVISION SYNCHRONIZING GENERATORS
AND METHODS OF MEASUREMENT

BY
ELDEN ROBERT VANDERBURG

Thesis
V16

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E. R. Vanderburg

Thesis
V16

FREQUENCY STABILITY STANDARDS
FOR TELEVISION SYNCHRONIZING GENERATORS
AND METHODS OF MEASUREMENT

by

Elden Robert Vanderburg
Lieutenant Commander, United States Navy

Submitted in partial fulfillment
of the requirements
for the degree of
MASTER OF SCIENCE

United States Naval Postgraduate School
Annapolis, Maryland
1950

This work is accepted as fulfilling
the thesis requirements for the degree of

MASTER OF SCIENCE

from the
United States Naval Postgraduate School.

PREFACE

For a period of eleven weeks, from 3 January to 18 March 1950, the author was associated with the Television Terminal Equipment Group, Engineering Products Department, Victor Division, of the Radio Corporation of America, at Camden, New Jersey. During this period a study was made of the effects of unstable synchronizing pulse frequency, a method of measurement was devised, and a circuit was designed which permits continuous monitoring of the synchronizing generator frequency behavior.

This work was undertaken at the suggestion of Mr. W. J. Poch, Group Manager of the Television Terminal Equipment Group. Mr. Poch stated the need for a simplified measuring method which utilized a monitor scope as the indicating device.

The author wishes to further acknowledge the advice and assistance given in connection with this work by Mr. J. M. Brumbaugh and other members of the Advance Development Group under Mr. H. N. Kozanowski.

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INTRODUCTION

Synchronism between television transmitters and receivers is perhaps the most important element of a television system. With the incorporation of frequency stable horizontal scanning oscillators in receivers the frequency stability of transmitter synchronizing signals becomes a matter of fundamental importance.

It will be the purpose of the following pages to give a complete presentation of the problems incident to the requirement for frequency stable synchronizing signals.

The first few pages are devoted to a brief review of those parts of the television system pertinent to the problem of synchronization so that the reader may have a more comprehensive insight into the reasoning behind the choice of synchronizing signal frequency standards.

Synchronizing signal frequency standards are discussed and the effects these standards have on studio and receiving equipment is analyzed. It is shown that the present standards are a fair compromise of ideal requirements.

Not much thought was given to possible methods of measurement when the standards were proposed or when later adopted. Available methods of measurement of synchronizing signal frequency and rate of change of synchronizing signal frequency are discussed. In general these methods have been unsatisfactory from an operational viewpoint.

A suggested method for making operational measurements of synchronizing signal frequency and rate of change of

frequency is presented along with a circuit developed for this purpose.

CHAPTER I

THE TELEVISION SYSTEM

1. Limitations

Noise is the most serious limitation in the television system as in the sound system, and in general arises from 2 sources; (1) shot noise in vacuum tubes and thermal agitation in vacuum tubes and other circuit elements, and (2) pickup from associated or remote electrical apparatus.

Resolution of a T.V. system is affected by noise but is more directly affected by the frequency bandwidth available for the transmission system. The Federal Communications Commission has set this bandwidth at 6 megacycles per second.

Lastly, there is the limitation imposed by the technological development of pickup and reproducing equipment. Economic considerations have prescribed in general that quality be stressed in transmitting equipment to provide reliability and reduce the need for including in receivers expensive corrective circuits.

2. Scanning

The standard scanning system in television requires the aperture to traverse the scene in essentially horizontal lines from left to right, and progressively from top to bottom. The aperture moves at constant velocity during actual scanning periods because this is a simple type of motion to duplicate in the reproducing aperture and because it provides a uniform light source in the reproducer.

During the retrace, or flyback period between lines the scanning beam moves extremely rapidly from the end of one line to the start of the next with a motion which need not be linear. Complete traversal of the scene must be accomplished at a rate high enough to avoid the sensation of flicker. Because most power systems in the United States are 60 cycle systems, and synchronization with the power system minimizes the effects of hum, and simplifies the problem of synchronizing rotating machinery in the television studio, 60 cycles has been chosen as the vertical scanning frequency.

To accomplish synchronism between the scanning aperture in the pickup and reproducing parts of the system, synchronizing information in the form of electrical pulses is provided during the otherwise wasted retrace interval between successive lines and successive pictures. Synchronizing pulses are generated at the studio and control the scanning of the pickup equipment as well as the scanning of the aperture in the receiving equipment when they are received as a part of the complete composite signal transmitted.

Vertical and horizontal resolving power of the system is, in part, a function of the number of scanning lines. Obviously, the ability of the system to resolve fine detail in the vertical direction will increase with the number of lines. However, as the number of lines increases, the bandwidth of the system must also increase to accomodate the

greater resolution required in the horizontal direction. Consideration of the related questions of channel width and resolution has resulted in the present day usage of 525 lines. A factor which influenced the choice of this particular number of scanning lines is the need for an exact integral relationship between horizontal and vertical scanning frequencies. This relationship is attained in the television system by the use of a series of electronic counters made stable by limiting the characteristic count of each to a small integer. For example, R.C.A. synchronizing generator equipment uses four counters, counting 7, 5, 5, and 3. The combined product of these 4 numbers is 525, the number of lines per frame. The product of 525 and 60 is 31,500 which is the master oscillator frequency. Another counter divides the master oscillator frequency by 2 to yield the required horizontal scanning frequency of 15,750 cycles per second.

To conserve bandwidth without sacrificing freedom from flicker a standard 2-to-1 interlaced system of scanning is the present practice. The sensation of flicker is related to the frequency of illumination of the entire scene, and has no relation to the number of lines nor to the frequency of the lines. Interlacing gives greater freedom from flicker by scanning half of the lines, uniformly distributed over the entire picture area during 1 vertical scan. Thus the effect of doubling the frequency of picture illumination is achieved without changing the velocity of the scanning

beam. The aperture scans alternate lines consecutively from top to bottom after which the remaining lines, that fall in between those included in the first operation, are scanned consecutively from top to bottom. A 13 line interlaced scanning system is illustrated in Figure 1. Each group of lines called a field consists of $262\frac{1}{2}$ lines, 2 consecutive fields constitute a complete picture or frame of 525 lines. Field frequency is 60 cycle, and frame frequency is 30 cycles per second. One fault of interlaced scanning is horizontal break-up illustrated in Figure 2.

The series of waves and pulses generated during the actual scanning line periods is the basic part of the television signal. During retrace periods the pickup tube may produce spurious signals which along with retrace lines detract from the reproduced picture. It is therefore desirable to add blanking pulses to the picture signal during retrace periods. Actually, blanking pulses are applied to the scanning beams in both the camera pickup tube and in the receiver reproducing tube. Camera blanking pulses are used only in the pickup tube and serve to close the scanning aperture during retrace. Picture blanking pulses are somewhat longer than camera blanking pulses and are made an integral part of the signal radiated to the receiver. Picture blanking pulses are simple rectangular pulses having a time duration slightly longer than the actual retrace periods in order to trim up the edges of the picture. They are produced in the synchronizing generator from the same basic

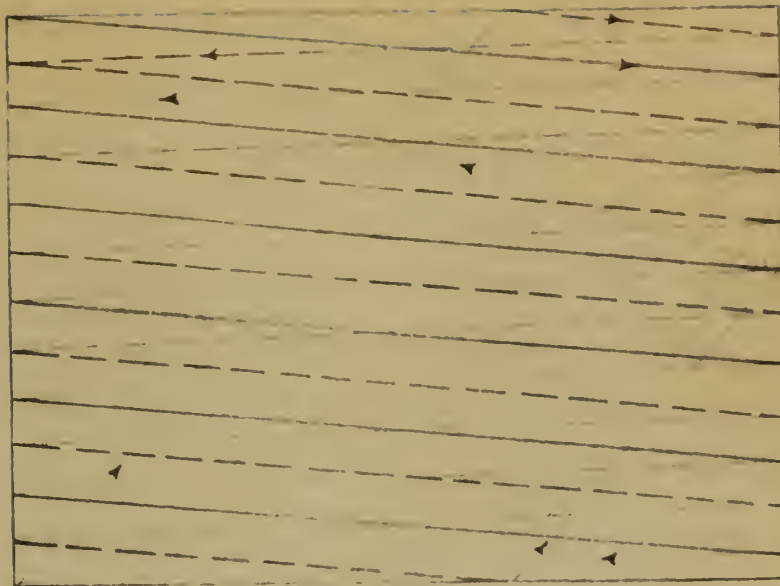


FIG. 1 Odd-line interlaced scanning system with 13 lines. Consecutive fields are indicated by solid and dotted lines, respectively.

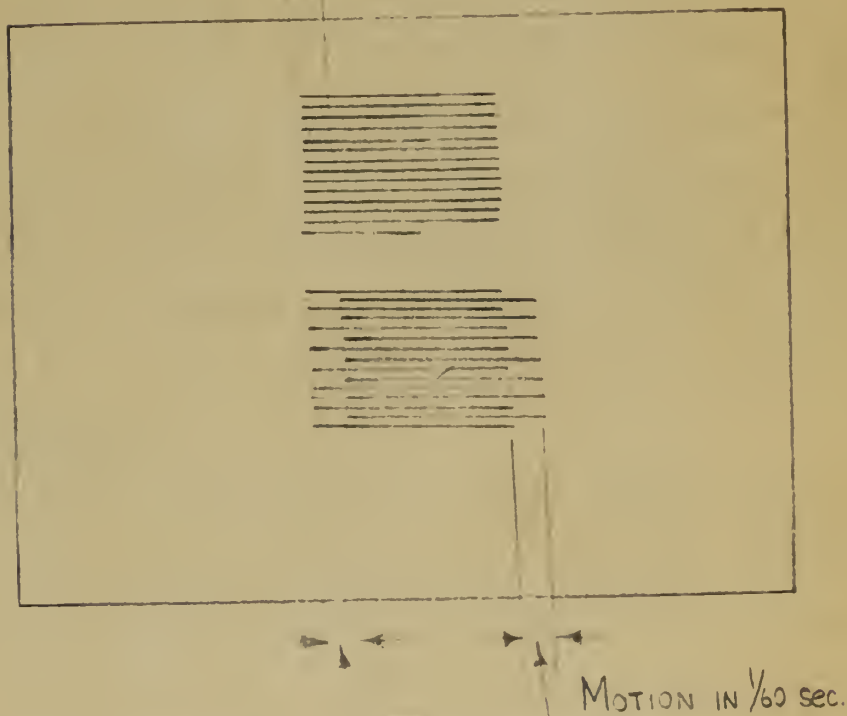


FIG. 2 Effect of horizontal motion on vertical edges in a 2-to-1 interlaced system. Upper object stationary. Lower object moving to right.

timing circuits which produce the scanning signals and are therefore accurately synchronized with the retrace periods. Horizontal blanking pulses recur at intervals of $1/15,750$ of a second and are no longer than 18 percent of the period between the start of successive scanning lines. At times corresponding to the bottom of the pictures, horizontal blanking pulses are replaced by vertical blanking pulses which are similar but have a duration approximately 15 scanning lines long. Both blanking pulses, with some detail, are shown in Figures 3 and 4.

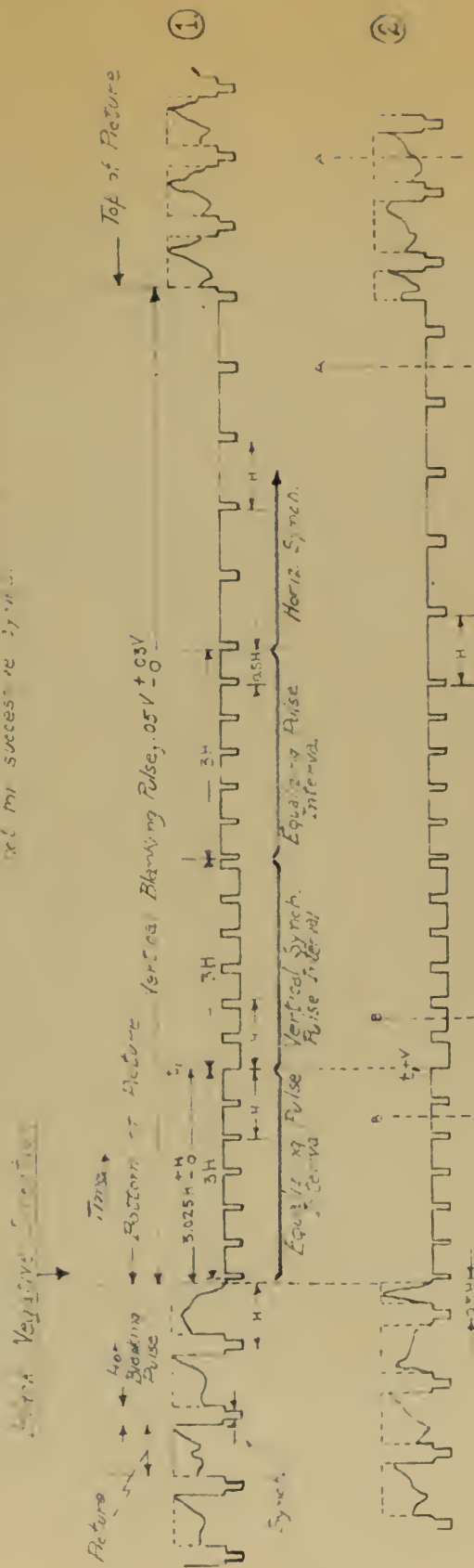
The width of the vertical blanking pulse is not limited by circuit considerations as is that of the horizontal pulse. The limitation in this case is the requirement of television film projectors of the intermittent type that the scene be projected on the pickup tube only during the vertical blanking period. Hence, the blanking period must be of sufficient duration so that there is adequate storage of photo-electric charges on the sensitive surface of the pickup tube.

3. Synchronization

The horizontal and vertical scanning systems in television receivers are two separate and independent circuits, each requiring accurate synchronizing information to keep them in step with the corresponding scanning system in the camera which originates the signal. The synchronizing system employed utilizes horizontal and vertical pulses of equal amplitude but of different wave shape. By this means

NOTES:

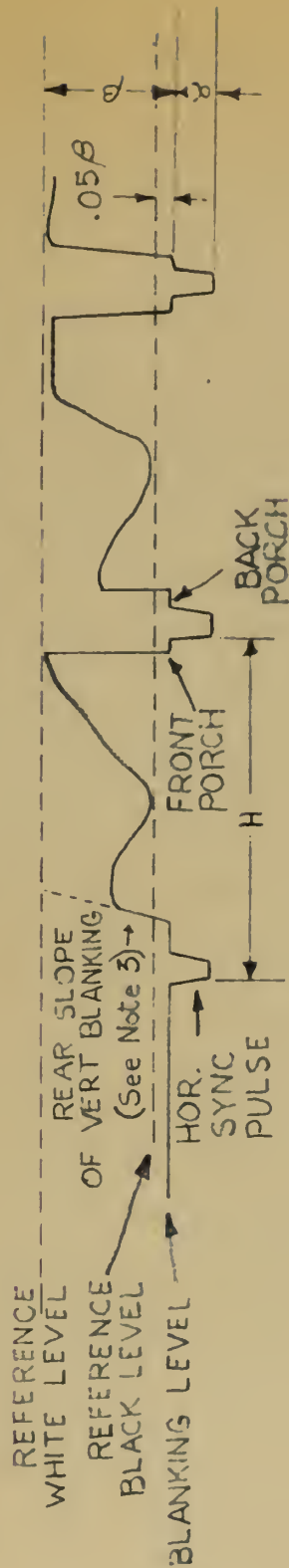
1. H = Time from start of one line to start of next line.
2. V = Time from start of one field to start of next field.
3. Leading and trailing edges of vertical sync pulse should be compared at 55 lines G.H.
4. All calculations and limits apply to any form of picture and not necessarily 17.71.



Picture Line Markings - Standard Output

Fig. 3

DETAIL BETWEEN A-A IN 2



NOTES:

5. Equalizing pulse area shall be between .045 and .05 of the area of a horizontal sync pulse.
6. All slope intervals to be measured between 0.1 and 0.2 amplitude reference lines.
7. All slope intervals shall be 0.0034 in.

DETAIL BETWEEN B-B IN 2

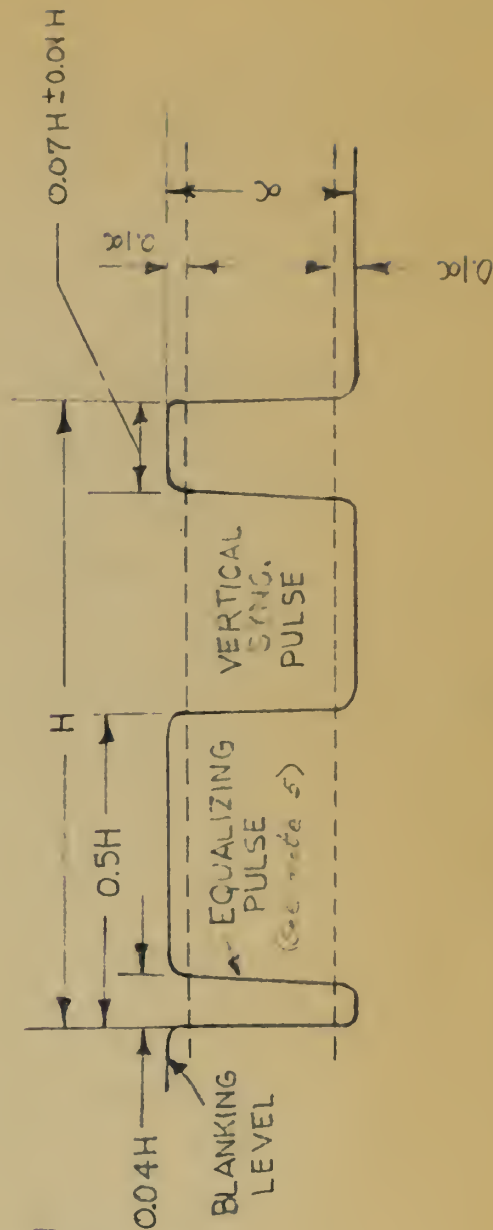


Fig. 4 Detail of Figure 3.

of synchronization the pulses may be added to the picture signal without overloading the transmitter or reducing the power available for the picture signal, and simple frequency discrimination may be used to separate the horizontal and vertical pulses. Figure 3 shows the addition of synchronizing pulses in the composite signal.

All synchronizing pulses appear below black level and hence can have no effect on the tonal gradation of the picture. Horizontal synchronizing pulses, except those occurring during the first portion of the vertical blanking period, are all simple rectangular pulses appearing at the negative base of the horizontal blanking pulses and during the latter portion of the vertical blanking pulses. The synchronizing pulses are considerably shorter than the blanking pulses, and their leading edge is set back from the leading edge of the blanking pulse forming a step in the composite pulse called the front porch. This off-set at the leading edge is made to insure that blanking has occurred before the synchronizing pulse initiates horizontal retrace, and to insure that any discrepancies which may occur in the leading edge of the blanking pulses do not affect either the timing or amplitude of the synchronizing pulses. The choice of pulse width of the horizontal synch, 8 percent of the period between the start of successive lines, was influenced by several factors. The width should be as great as possible to make the energy content of the pulse large when compared to the worst noise interference. The width should be no greater than necessary to meet the above con-

dition so that average power requirements of the transmitter may be minimized. Finally, the pulse width should be as narrow as possible to facilitate discrimination between the horizontal pulses and the wider vertical pulses.

Vertical synchronizing pulses are basically rectangular in shape and are much longer than horizontal pulses. In addition, each pulse is cut by 6 slots making it appear to be a series of 6 wide pulses at twice horizontal pulse frequency. The slots contribute nothing to the vertical synchronizing information but do provide a means of providing continuing horizontal synchronizing information. Preceding and following the vertical pulse are groups of 6 narrow equalizing pulses at twice horizontal frequency whose purpose is also to provide continuous horizontal synchronizing information. Doubling the frequency of the equalizing pulses and the slots in the vertical pulse provides an arrangement whereby the choice of proper alternate pulses makes available some type of horizontal synchronizing information at the end of each horizontal scanning line in either even or odd fields. This arrangement also makes the vertical synchronizing interval and both equalizing pulse intervals exactly alike in both even and odd fields. It should be noted that the leading edge of the horizontal synchronizing pulses and of the equalizing pulses, and the trailing edge of the slots in the vertical pulse are responsible for triggering the horizontal retrace in the receiver.

A most difficult problem in synchronizing is that of maintaining accurate interlacing. Discrepancies in either

the timing or amplitude of the vertical scanning of alternate fields will cause displacement in space of the interlaced field. This effect known as pairing causes non-uniform spacing of the scanning lines, reduction in vertical resolution, and intensification of the line structure in the picture. The presence of minute 30 cycle component in the vertical scanning will cause pairing. Since alternate fields are displaced with respect to each other by half a line, the horizontal synchronizing signal will have an inherent 30 cycle component. It is this situation and the need to prevent the transfer of the 30 cycle component into vertical deflection which accounts for the introduction of the double frequency narrow equalizing pulses. Vertical synchronizing pulses are separated from the composite synchronizing signal by suppressing the horizontal synchronizing pulses in an integrating network. The equalizing pulses cause the integrating network to "forget" the difference between alternate fields by the time the vertical synchronizing pulses begin. Equalizing pulses are made with half the width of normal horizontal pulses so that at the transition from normal horizontal pulses to equalizing pulses at double frequency, the a-c axis of the synchronizing signal does not shift.

CHAPTER II

SYNCHRONIZING SIGNAL FREQUENCY STABILITY CONSIDERATIONS

1. Receiver Requirements

Horizontal scanning circuits of most receivers are equipped with automatic frequency control in order to neutralize the deleterious effects of noise. In contrast to triggered circuits where each scanning line is individually initiated by a pulse in the incoming signal, A.F.C. scanning is governed by stable oscillators which in turn are controlled by voltages obtained from phase comparison of the incoming synchronizing pulses and the scanning signals themselves. The time constant of the comparison circuit must be made long compared to the scanning period so that random noise has little effect on the resulting control voltage. Such A.F.C. circuits are keyed to provide further immunization against noise by eliminating all noise pulses except those occurring during the short keying interval.

As a result of A.F.C. scanning circuits in receivers, a very high order of frequency stability is required in the horizontal synchronizing and blanking signals. Frequency modulation of the horizontal pulses is intolerable because it causes the right and left hand edges of the blanked raster as well as vertical lines in the scene to assume the same shape as the modulating wave. Since retrace timing is controlled by a stable oscillator which is not responsive to short time changes of the synchronizing timing, horizontal retrace begins along a straight line. Variation in

synchronizing timing shows as a displacement of vertical objects in the televised scene and in the edges of the raster.

2. Studio Requirements

As was stated in the foregoing chapter, the vertical scanning frequency is locked in with the 60 cycle power mains to minimize hum effects and to simplify the synchronization of rotating machinery. The effect of hum pickup in studio equipment, principally in the low level stages of the video amplifiers, is to put a horizontal sinusoidal intensity gradation in the televised picture commonly referred to as a hum bar. If the vertical scanning frequency is locked to the 60 cycle power supply frequency, the hum bars will remain fixed in phase and consequently they will remain stationary across the picture. They can then be virtually eliminated by the addition of corrective sawtooth and exponential voltages to the composite signal, i.e., the hum bars are made to fade into the background shading. However, if there is no lock-in, hum bars will slip across the picture with a speed dependent on phase difference and corrective shading is impossible. Even without the benefit of corrective shading, stationary hum bars are much less objectionable than those in motion. Hence, power main lock-in makes hum pickup at receivers less noticable in those cases where transmitter and receivers operate on the same or synchronized power systems.

3. Standards

Because of the conflicting requirements of high hori-

zontal synchronizing pulse stability and synchronizing generator lock-in with power line frequency, minimum standards for synchronizing signal tolerance have been adopted. These standards are as follows:

It shall be standard that the time of occurrence of the leading edge of any horizontal pulse "N" of any group of twenty horizontal pulses not differ from "NH" by more than $0.001H$ where "H" is the average interval between the leading edges of horizontal pulses as determined by an averaging process carried out over a period of not more than 100 lines.

It shall be standard that the rate of change of the frequency of recurrence of the leading edges of the horizontal synchronizing pulses appearing in the picture line amplifier output be not greater than 0.15 percent per second, the frequency to be determined by an averaging process carried out over a period of not less than 20 or more than 100 lines, such lines not to include any portion of the vertical blanking signal.

It shall be standard that the frequency of horizontal and vertical scanning pulses not vary from the values established by the standards of frame frequency and number of scanning lines by more than ± 1 percent regardless of variations in frequency of the power source supplying the television station.

The standard for the change in timing between successive horizontal pulses is in need of revision. This standard was written in the days when synchronizing pulses were picked off of a rotating scanning wheel. Counter circuits in present use are not restricted by it. The standard for rate of change of scanning frequency is considered a fair compromise. It is low enough so that satisfactory automatic frequency control circuits with good noise immunity can be used, and it still permits the scanning frequency

to be shifted rapidly enough to follow the variation in frequency of a large power system without more than a few percent variation in phase relationship between the 60 cycle power wave and the vertical blanking signal of the synchronizing generator. The standard specifying the limits of drift of the synchronizing frequency principally provides a manufacturing tolerance on receiver automatic frequency control circuits. Under normal conditions large power systems will not exceed this frequency standard. Should unusual circumstances create a condition which made power frequency run for extended periods outside the limiting frequencies of 59.4 to 60.6 cycles per second, it would be necessary to switch the synchronizing generator from 60 cycle to crystal control.

The standard for rate of change of scanning frequency is the critical operating standard. To maintain the least phase difference between the vertical blanking or scanning pulse, and the projection equipment exposure pulse, which is desired during vertical blanking, the synchronization lock-in time constant should be made as fast as possible. The time constant setting must be fast enough to keep the phase difference between vertical synch, derived from the master oscillator, and power supply frequencies within half a cycle or the lock-in circuit will lose control. However, it is not uncommon for power line frequency to vary quite erratically within the limits established for maximum drift, and the time constant setting must not permit the master oscillator to follow so rapidly that the maximum allowable

rate of change of synchronizing pulse frequency is exceeded.

4. Synchronizing Generator Lock-in Circuit

To facilitate an understanding of synchronizing generator lock-in control, a brief description of a typical lock-in circuit employed in R.C.A. TG-1A Studio Synchronizing Generator equipment can be given with the aid of the simplified diagram of Figure 5. The frequency of the master oscillator is determined by plate current in the reactance tube. Bias for the reactance tube is obtained from the 60 cycle lock-in circuit, which compares the 60 cycle output pulse from the generator counters with the 60 cycle supply voltage, and converts any phase difference into a d.c. voltage.

The 60 cycle supply voltage, after clipping, is applied to one corner of the lock-in bridge through the A.F.C. time constant switch, S-1, as a square wave. The opposite corner of the bridge is connected through the 60 cycle position of the frequency control switch, S-2, to the grid of the reactance tube. The 60 cycle pulse from the synchronizing generator is applied to the 2 remaining corners of the bridge through a transformer, T-1, which has its secondary connected in series with the parallel combination of R4-C4.

When the 60 cycle pulse occurs, all the diodes are caused to conduct, thus making possible a transfer of current in either direction between input and output terminals of the bridge. The 60 cycle pulse also creates a charge across the combination R4-C4 which is negative toward the double plate corner of the bridge, and keeps the diodes

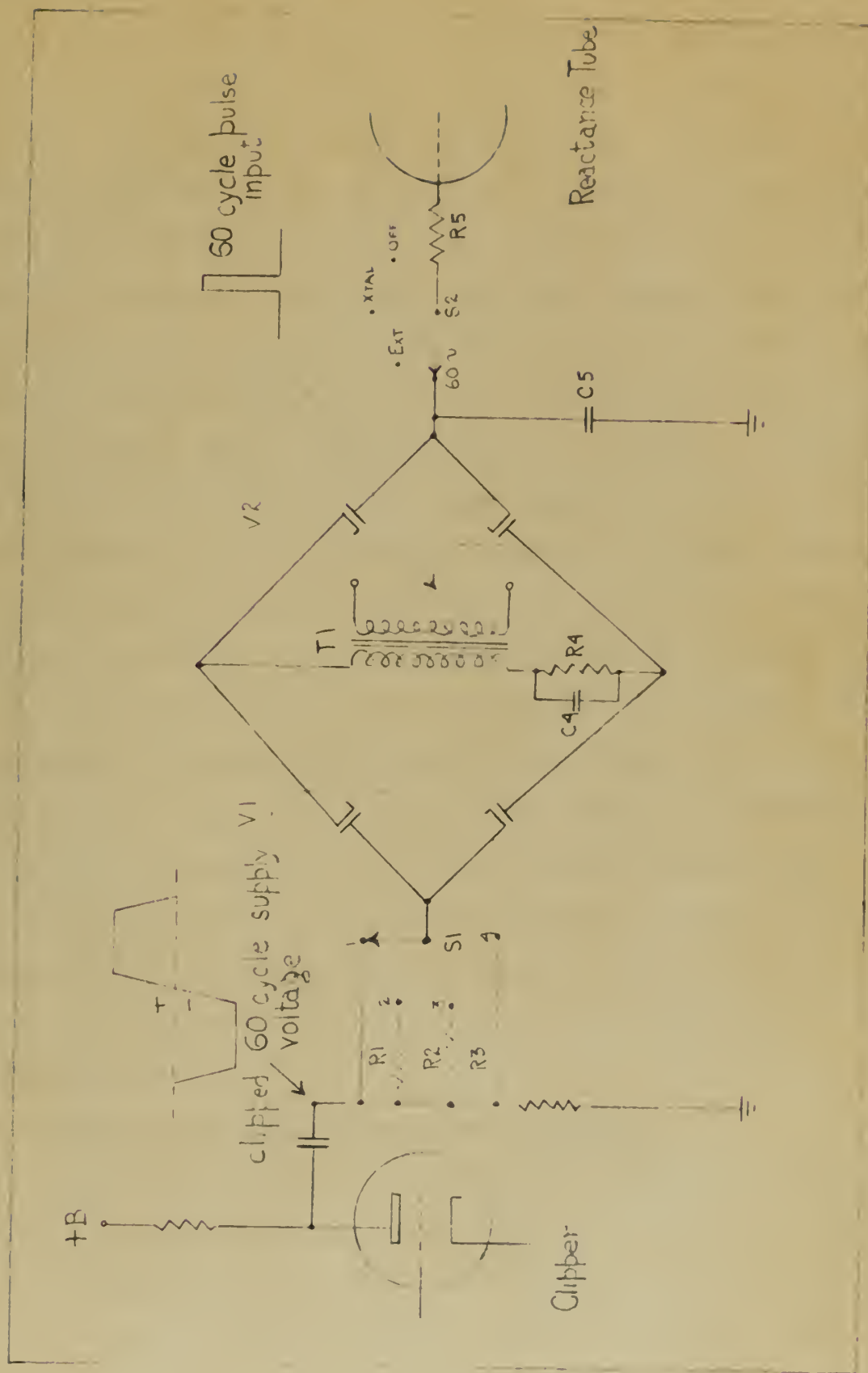


FIG. 5 RCA TG-1A Synchronizing Generator Lock-in Bridge Circuit.

non-conducting during the interval between pulses. The master oscillator frequency is adjusted to 31,500 cycles per second when the voltage on the reactance tube is zero. If the frequency is exactly 31,500 cycles, the square wave voltage applied to the bridge will be passing through zero when the pulse from the counters causes the diodes to conduct. No current will pass through the bridge circuit under these conditions. When the frequency is slightly higher than 31,500 cycles per second, the resultant pulse will occur sooner, while the square wave is negative. Current will be passed through the bridge, placing a negative charge on condenser C5, and therefore on the grid of the reactance tube, thereby reducing its mutual conductance and bringing about a reduction in the frequency of the master oscillator. A similar action takes place when the frequency of the master oscillator is slightly lower than 31,500 cycles per second. The speed at which the charge on the reactance tube grid follows changes in the relation between supply voltage and master oscillator frequencies depends on the size of the R-C combination in the grid return circuit of the reactance tube, hence on the position of the time constant switch S-1.

5. Effect of Erratic Power Line Frequency

It is not uncommon for power line frequency to make sudden shifts with changes in load. As a matter of academic interest assume the power main frequency to suddenly jump from one value to another. If the frequency jumps its maximum allowable limit from 59.4 to 60.6 cycles per second,

and if there is continuous maximum df/dt , rate of change of frequency of the synchronizing generator, 13.34 seconds will be required for lock-in. Since normal horizontal scanning frequency is 15,750 cycles per second, the allowable maximum df/dt is equal to 0.0015 times 15,750 or 23.6 cycles per second per second. Then from,

$$f_2 = f_1 + (df/dt)t$$

where, f_2 = final frequency

f_1 = initial frequency

df/dt = rate of change of frequency

t = time

$$t = 13.34 \text{ seconds.}$$

During these 13.34 seconds, a total of 8 hum bars would move across the televised scene. The number of lines, n , scanned in a given time, t , is given by the equation,

$$n = \int_0^t f_2 dt$$

$$n = f_1 t + \frac{1}{2}(df/dt)t^2$$

The number of hum bars, N , which will move across the scene is given by the expression,

$$N = \frac{f_2 t - f_1 t - \frac{1}{2}(df/dt)t^2}{f_0 t_0}$$

where, f_0 = average frequency, or in this case the nominal standard frequency, 15,750 c.p.s.

t_0 = time for 1 field, 1/60 sec.

$$N = \frac{(315)(13.34) - (1/2)(23.6)(13.34)^2}{262.5} = 8$$

However, consideration of lock-in circuit action discloses that the discriminator output to the reactance tube changes polarity after a slip of $1/2$ a hum bar and gives a negative correction. The synchronizing generator could never lock-in under these conditions. Hold-in of control will be maintained, and proper phase restored on sudden shifts of line frequency only if full frequency correction can take place within a slip of $1/2$ hum bars. Thus, the maximum sustained instantaneous shift in power line frequency for which lock-in can be maintained may be calculated from a simultaneous solution of the following 2 equations:

$$f_1 = f_0 + (df/dt)t_1$$

$$f_1 t_1 - f_0 t_1 - \frac{1}{2}(df/dt)t_1^2 = 131.25$$

then, $t_1 = 3.33$ seconds

and, $f_1 - f_0 = 78.5$ c.p.s.

The percentage frequency jump is therefore,

$$\frac{f_1 - f_0}{f_0} \times 100 = 0.497\%$$

Hence, lock-in can be maintained for sustained jumps in line frequency of 0.298 cycles. Increasingly larger jumps in line frequency can be tolerated for shorter periods than that established in the above calculation provided the phase difference between the 60 cycle pulse from the synchronizing generator, and the comparison voltage from the power supply does not exceed a half cycle. The curves of Figure 6 show the relationship between tolerable line frequency surge and surge duration.

While the conditions specified in making the fore-

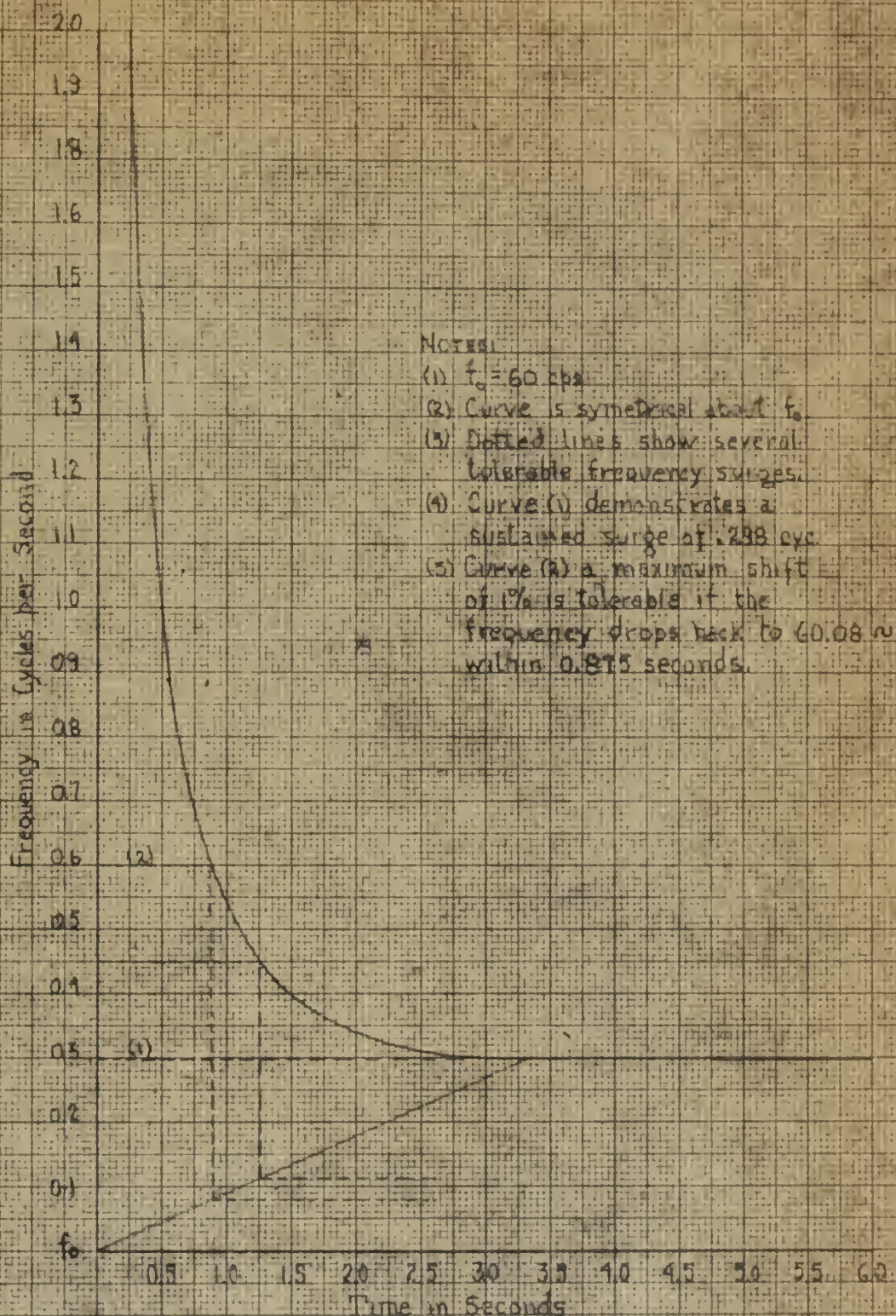


FIG. 6 Curve showing relationship between tolerable line frequency surge and duration.

going calculation may never occur in actual practice, they are a fair enough approximation that the results demonstrate the need for maintaining as fast a time constant setting on the synchronizing generator lock-in circuit as is possible within tolerance. Should power line frequency surges exceed tolerable limits shown by the curves of Figure 6, it would be necessary to increase the follow-up speed of the lock-in circuit and exceed the minimum standard established for rate of change of horizontal synchronizing pulses, or switch the master oscillator to crystal control.

6. Effect Which Maximum df/dt of Horizontal Synch May Produce in a Television Picture.

To assist in understanding the effect the maximum rate of change of horizontal synchronizing pulses may produce in a received television picture, the following calculation has been made to show the effect produced by sinewave frequency modulation applied to the horizontal synchronizing pulses with a peak amplitude corresponding to the maximum allowable rate of change given by the standard. Let

$$df/dt = 23.6 \cos \omega t$$

where, f = horizontal scanning frequency

$\omega = 2\pi \times$ frequency of applied sinewave of frequency modulation, f_m .

Integrating this expression one gets an equation for the horizontal scanning frequency,

$$f = f_0 + \frac{23.6}{\omega} \sin \omega t,$$

where, f_0 = average horizontal scanning frequency.

Assume the television receiver in use to have a horizontal oscillator locked in with an A.F.C. circuit having a time constant sufficiently long so that its frequency always corresponds to f_0 . The result will then be that normally straight vertical lines in the picture will have a displacement from a straight line varying in time at the frequency of the applied modulation. This displacement from a straight line is found by integrating the second part of the above expression for frequency,

$$\begin{aligned} D &= \int \frac{23.6}{\omega} \sin \omega t \, dt \\ &= - \frac{23.6}{\omega^2} \cos \omega t. \end{aligned}$$

The following table shows the value of the maximum displacement, D , obtained for several values of the modulating frequency, f_m :

<u>f_m</u>	<u>Max. D</u>
60	.000166 cycle
30	.000664
20	.00149
10	.00598
5	.0239

One of the most troublesome types of frequency modulation encountered in synchronizing generator output signals is frequency modulation traceable to the power supply frequency. From the above table it is seen that the depar-

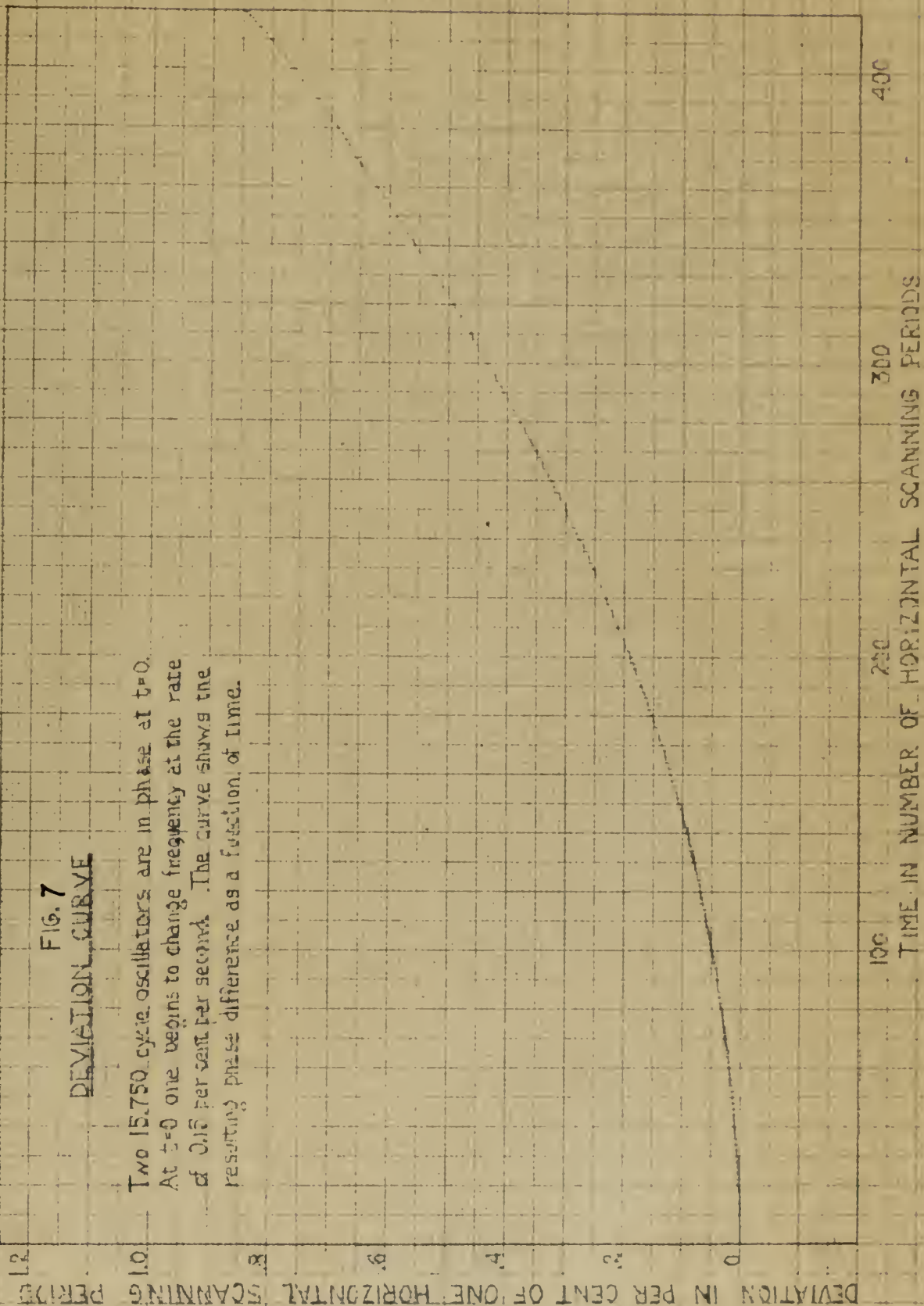
ture from a straight line allowed by the present standard is only 0.0166% of the period for 1 horizontal line. Assuming the receiver to have a 4.5 megacycle bandwidth there will be approximately 570 picture elements per line. Therefore, the maximum allowable displacement for the case of 60 cycle modulation is approximately one tenth of a picture element. It is questionable if this small displacement could be visually detected on the best receivers. In the case of 30 cycle modulation however, the maximum displacement would be four tenths of a picture element, and 2 successive fields would have the displacement in opposite directions so that at one point in the raster a total displacement of eight tenths of a picture element would be possible.

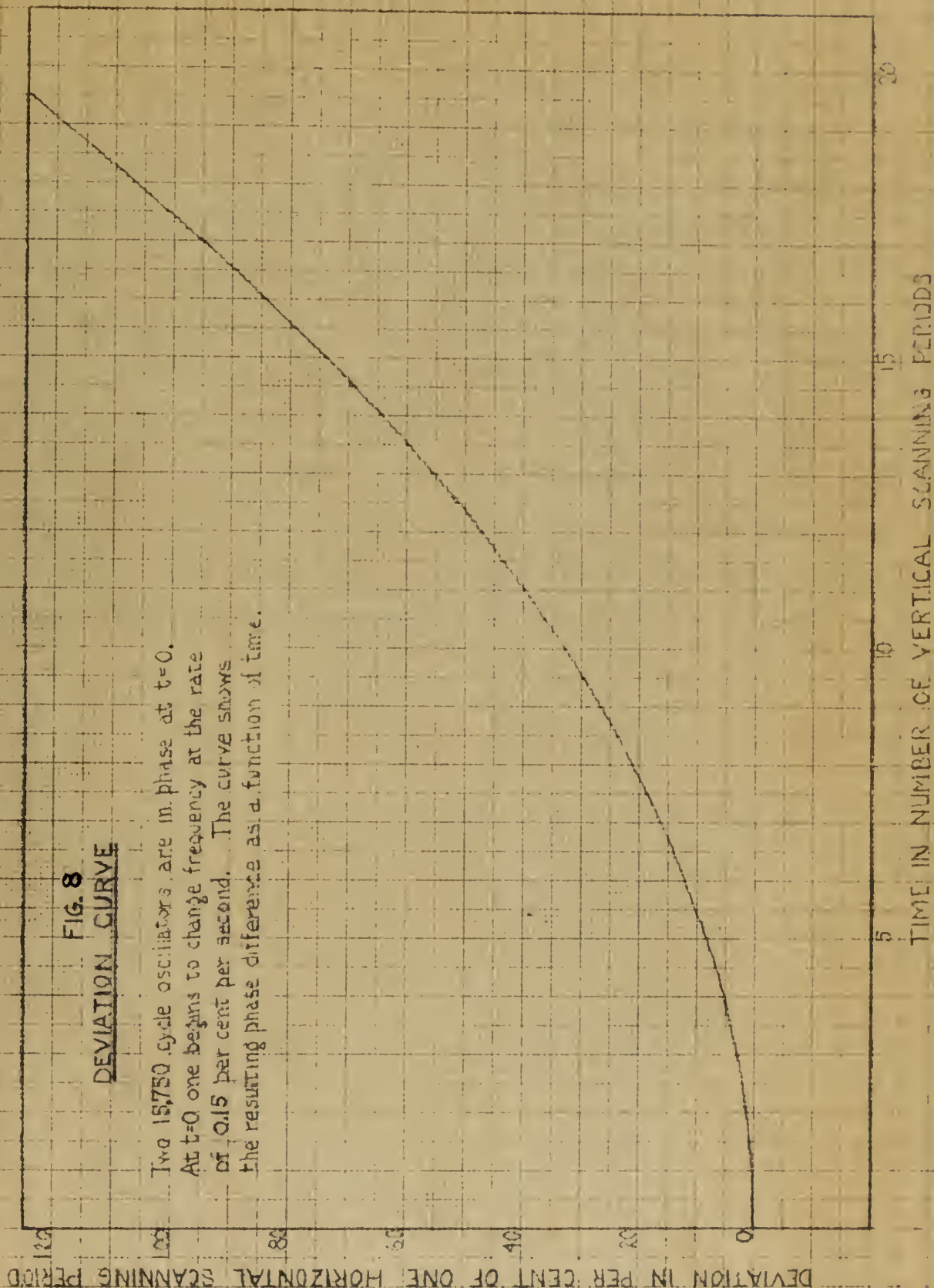
The curves of Figures 7 and 8 have been calculated to show the effect continuous maximum uniform rate of change of horizontal synchronizing pulses will have on a received television picture. The receiver horizontal scanning oscillator and received synchronizing pulses are assumed to be in phase and at the nominal standard frequency of 15,750 c.p.s. at time equal to zero. At time equal to zero the synch frequency begins to change frequency at the maximum allowable rate of 0.15 percent per second while the receiver oscillator holds constant at 15,750 c.p.s. because of long time constant A.F.C. discriminator action. The phase difference between the two frequencies is calculated from the equation,

$$d = \frac{1}{2}(df/dt)t^2$$

FIG. 7
DEVIATION CURVE

Two 15.750 cycle oscillators are in phase at $t=0$.
At $t=0$ one begins to change frequency at the rate
of 0.1% per cent per second. The curve shows the
resulting phase difference as a function of time.





where "d" is the deviation in cycles per second.

From the curve of Figure 7 it can be seen that a normally straight line in the televised picture will be displaced at the bottom of the first field by approximately 0.33 percent of a horizontal scanning line, or by approximately two picture elements. This displacement will be evident between successive fields and result in a loss of horizontal resolution. The curve of Figure 8 shows long time deviation and assumes no correction of phase difference by the receiver oscillator. If the studio should switch pickups at such a time that the horizontal synch shifted 50 percent of a horizontal scanning line, it is seen from this curve that the maximum time for lock-in with the new synchronizing signal is approximately 5 seconds.

CHAPTER III

FREQUENCY MEASUREMENT OF SYNCHRONIZING SIGNALS

1. Average Repetition Rate of Synchronizing Pulses

Measurement of the repetition rate of the line and field synchronizing pulses in the output of a television transmitter serves as a check on the frequency dividing circuits in the synchronizing generator, and as a check on the minimum operating standard that the frequency not vary more than ± 1 percent. This measurement is relatively simple and the standard method is to compare the horizontal and/or vertical synchronizing pulses with a sinewave signal from a signal generator by means of a cathode ray oscilloscope. For continuous monitoring purposes, each divider stage in the synchronizing generator may be equipped with a small cathode ray tube to indicate its frequency division, thus making any change in division of any stage immediately apparent.

2. Rate of Change of Frequency of Horizontal Synchronizing Pulses

The measurement of rate of change of frequency of horizontal synchronizing pulses is a more complicated problem than that of measuring the average or instantaneous frequency. It is questionable if a completely satisfactory operational measurement has been devised. One method of measurement which has been reduced to practice is outlined below but it can be readily seen that it is most useful as a laboratory procedure. An independent reference oscillator of very high frequency stability is set at or very close to

a submultiple of the average horizontal synch frequency and is used to synchronize a cathode ray oscilloscope sweep. The connection of apparatus is shown in Figure 9. The

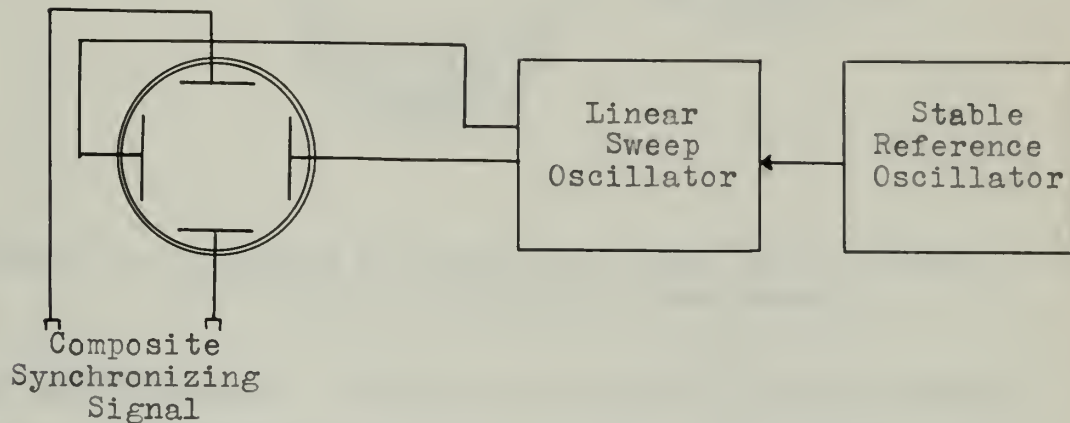


Figure 9. Equipment set-up for rate of change of frequency measurement.

cathode ray oscilloscope face is masked to block off all but the tips of the synchronizing pulses as illustrated in Figure 10. A camera with a motor drive is used to photograph the trace on 35 millimeter film. When the film is moved at a constant speed in a vertical direction, a line is traced on the film by the top of each horizontal pulse. The position of the line will vary in accordance with the shift in phase of frequency of the pulse relative to the output of the reference oscillator. Vertical synchronizing pulses interrupt the horizontal pulse traces, but provide convenient time marks. The slope of each trace relative to the vertical on the oscillogram is inversely proportional to the frequency difference between the submultiple of synchronizing pulses and the reference oscillator.

The change in slope is proportional to the rate of change

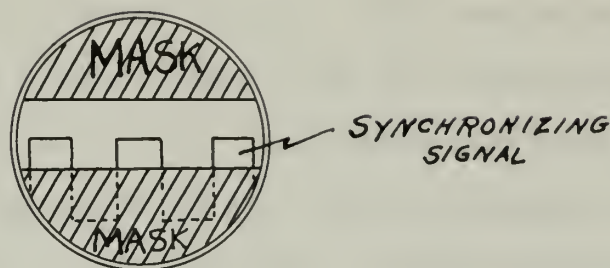
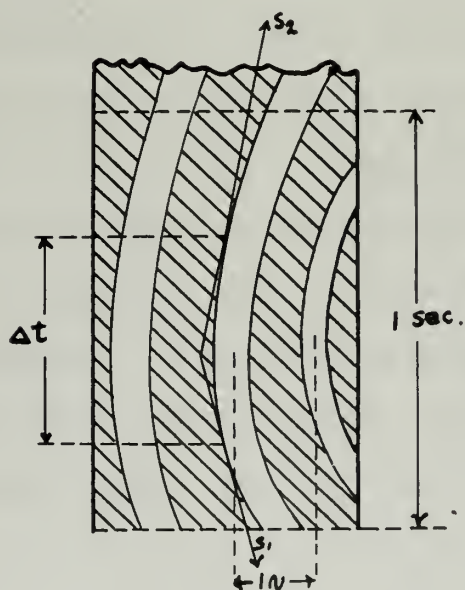


Figure 10. Masking of cathode ray tube face for rate of change of frequency measurement.

of this frequency. If the two slopes S_1 and S_2 change during a period of time, Δt , then, as shown in Figure 11, the average rate of change of frequency over the period, Δt , is

$$\frac{S_1 - S_2}{\Delta t}$$



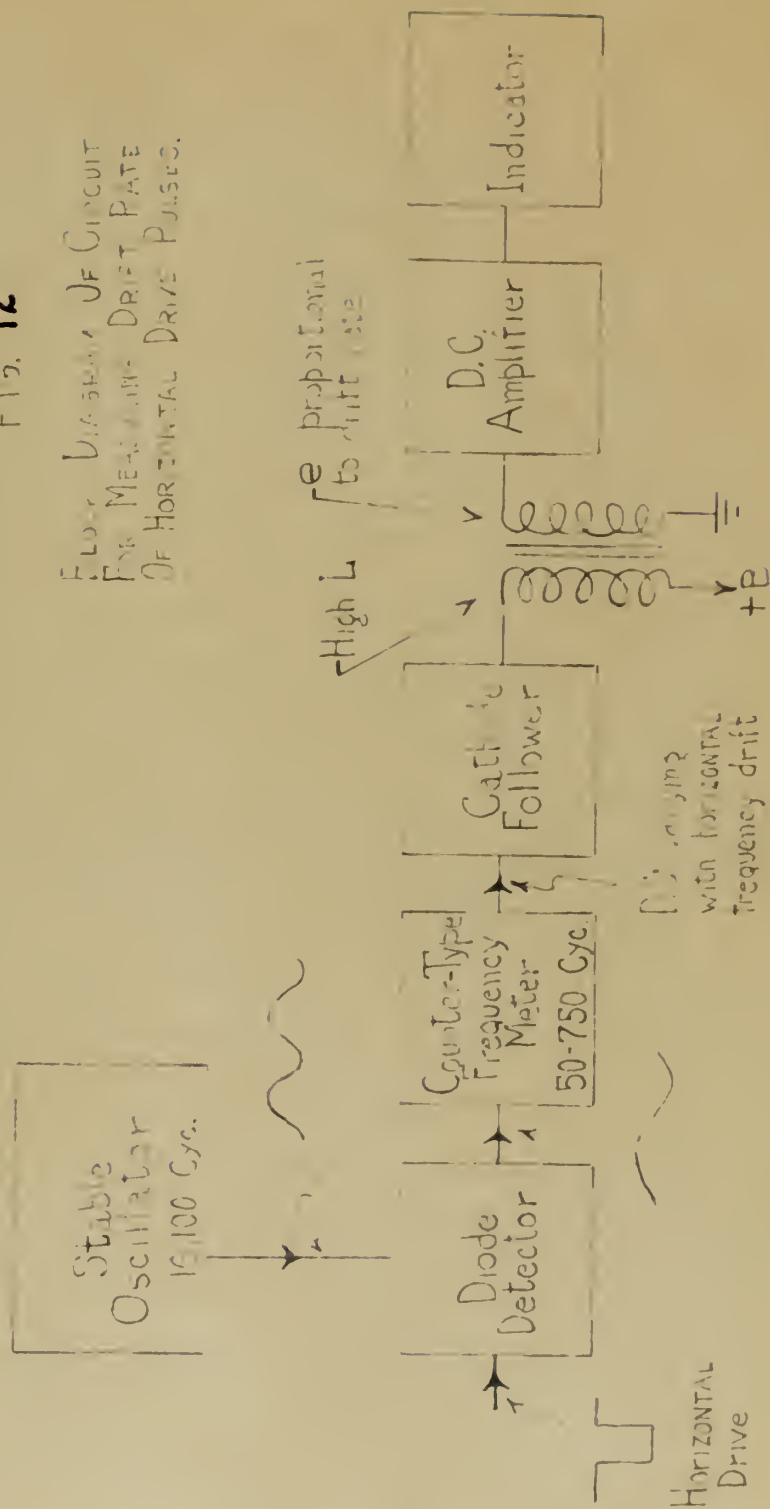
$$\text{RATE OF CHANGE} = \frac{S_1 - S_2}{\Delta t}$$

Figure 11. Graphical determination of the rate of change of frequency of horizontal synch pulses from oscillogram.

The block diagram of Figure 12 outlines a scheme which has been devised for making an operational measurement of horizontal pulse frequency drift. This system monitors the horizontal drive signal rather than the synchronizing signal, because the former is a continuous and periodic wave without extra components at the field frequency, and its lock-in with synchronizing pulses is sufficiently tight that its drift may be used to measure synch drift. The horizontal drive signal is heterodyned down to an average frequency of 400 cycles per second and applied to a frequency meter which gives a d-c voltage output proportional to synch frequency. Using this voltage to drive a cathode follower provides a source of current which is proportional to frequency. Differentiation of this current in a large inductor gives $e = di/dt$, which is thus proportional to df/dt , or rate of change of frequency. This output voltage can be indicated on a meter, an electron eye tube, or other suitable indicating device after amplification. In experiments with this set-up, a high speed VU meter with the rectifier removed was used as the indicating instrument, and while the response was too slow for completely satisfactory measurement, the set-up was adjudged sufficiently accurate for practical measurements. Calibration was obtained by taking steady state reading of horizontal drive frequency from the synchronizing generator for various values of d-c voltage on the reactance tube grid, and plotting the resultant. This grid potential was then varied at a constant known

Fig. 12

Flow Diagram of Circuit
For Measuring Drift Rate
Of Horizontal Drive Pulses.



rate, by means of a very long time constant discharge circuit, over a linear portion of the frequency vs. grid-potential curve, and the meter indication noted. In this way, meter indications were found for various values of df/dt .

A third possible approach to the problem of rate of change of frequency measurement would be to arbitrarily shift the phase of the 60 cycle power wave used for locking the synchronizing generator to the power supply a certain definite amount, and then to measure the time necessary for the synchronizing generator to reach stability. If this time interval is less than a certain minimum, the tolerable rate of change of frequency will be exceeded. Such a procedure would give data on the follow-up characteristic of the synchronizing generator and its lock-in circuit, but would be useless as an operational measurement.

3. Recommended Operational Method of Measurement of Average Repetition Rate and Rate of Change of Frequency of Horizontal Synchronizing Pulses.

The schematic diagram of Figure 13 is that of a circuit designed by the author to be used for operational measurement of horizontal synch pulse frequency and rate of change of frequency. This circuit is used in conjunction with a studio monitor scope as the indicating device. The input at J1 is the vertical drive pulse from the synchronizing generator. Stages including vacuum tubes V1 through V5 select alternate vertical drive pulses and use its stable leading edge to generate a narrow adjustable width pulse. The waveforms of Figure 14 indicate the action of these

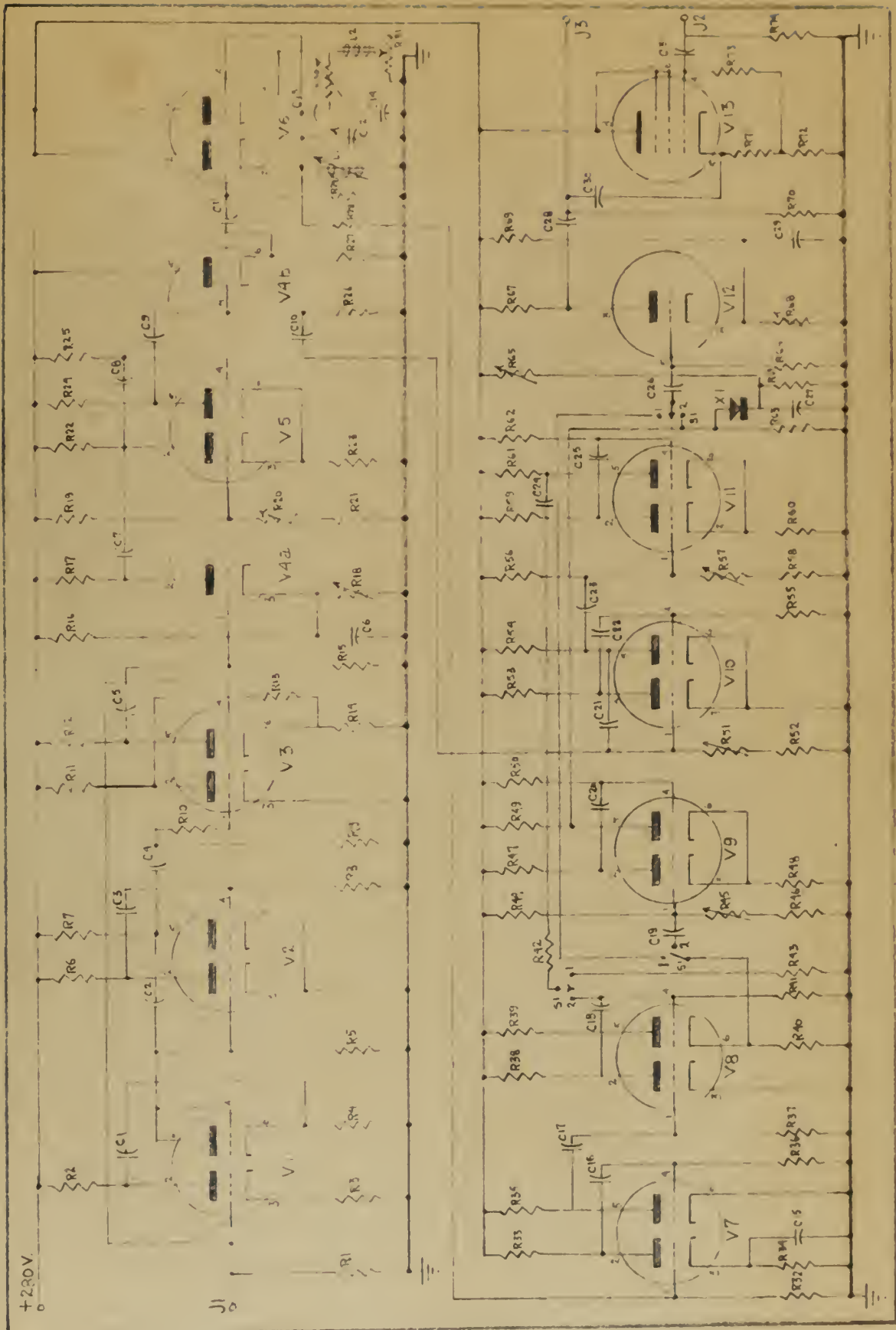
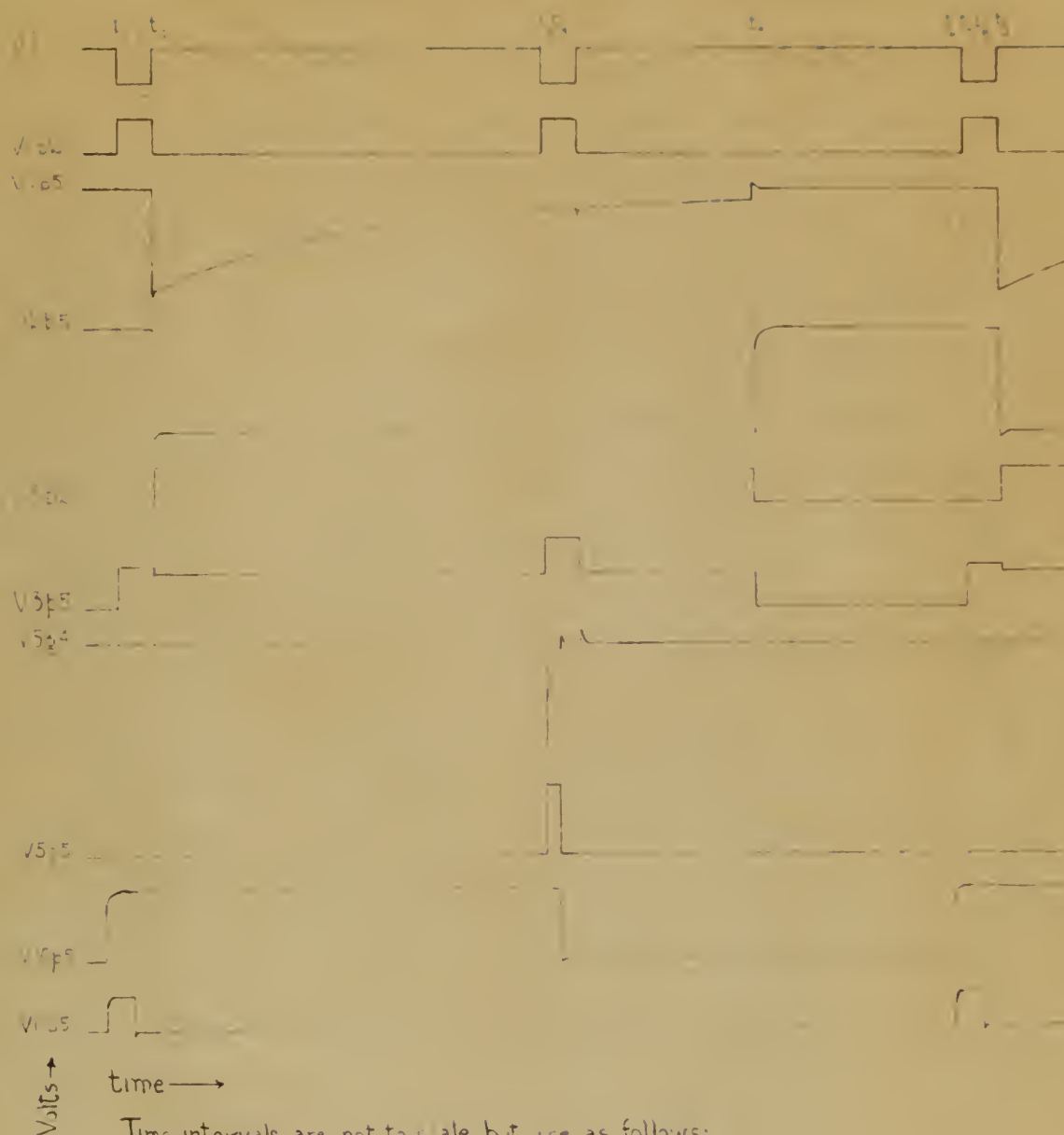


Fig. 13

FREQUENCY MEASUREMENT CIRCUIT



Time intervals are not to scale but are as follows:

t_1-t_2	444.5 microseconds	
t_1-t_3	± 16667	" , dependent on Sync Gen. frequency drift
t_2-t_5	± 21000	" , not critical
t_3-t_4	± 200	"
t_6-t_7	± 250	"
t_6-t_8	± 500	"

Voltage amplitudes are not to scale.

Waveform identification is as follows: Vp2; tube 1, plate, pin 2.

FIG. 14 Idealized Waveforms of Frequency Measurement Circuit.

stages. V6 is a stable keyed oscillator tunable by means of variable air condenser C12 from approximately 15,500 to 16,000 cycles per second. The oscillator is keyed off for approximately 3 cycles and on with a fixed phase relationship with the first horizontal pulse of each frame. R20 varies the width of the keying pulse, and hence makes this phase relationship adjustable. With S1 in position 1, the oscillator output is amplified, clipped, and peaked in V7 and V8. V12 provides a low impedance output to the mixer stage V13, and by means of R68 provides a pulse amplitude control. The stable pulse from the oscillator is mixed with the composite picture signal in V13 and the combined output at J3 is fed into the studio monitor scope.

The resultant addition to the monitor picture is a narrow black line, less than 1 picture element in width. If the horizontal synchronizing pulse frequency, and the keyed oscillator frequency are the same this line will be solid and vertical, see Figure 15, line A-B. Point A can be varied across the top of the picture by adjusting the width of the oscillator keying pulse. If the synchronizing pulse frequency is higher than the oscillator frequency the solid vertical line A-B will degenerate into two dotted sloping lines such as shown by the dashed lines A-C and D-E, Figure 15. The slope is a function of the difference in frequency. The lines are dotted because of interlaced scanning, i.e., A-C and D-E are generated by successive fields. Point D will be displaced to the right of point C a distance proportional to the slope of A-C and the duration of the ver-

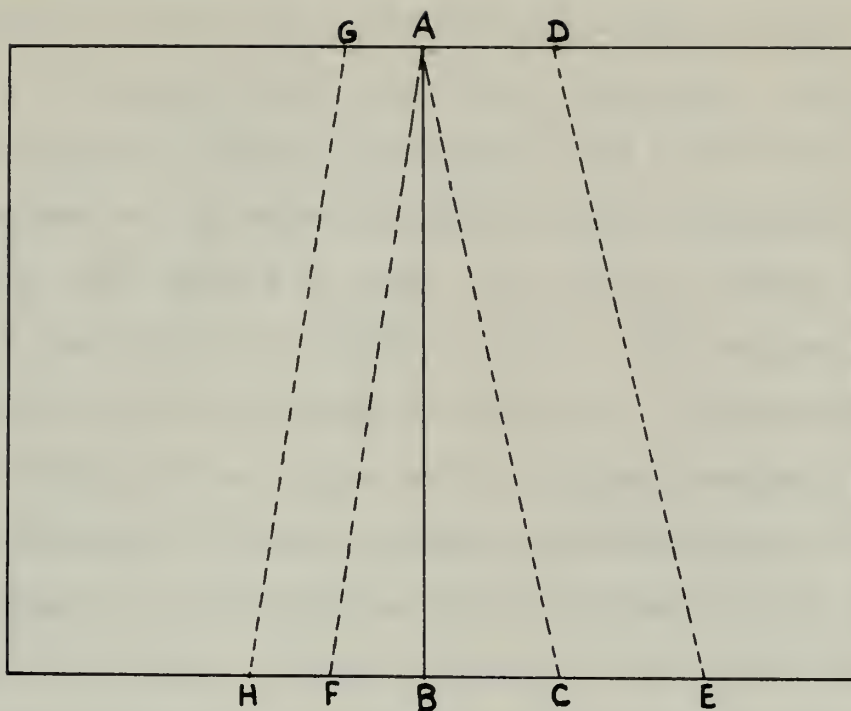


Figure 15. Frequency measurement indication on face of monitor scope.

tical blanking period. Lines A-F and G-H represent the case of synchronizing pulse frequency lower than oscillator frequency. By tuning the keyed oscillator for the solid vertical line indication the frequency of horizontal synchronizing pulses can be read from the calibrated tuning dial. Deformation of this vertical line is an indication of frequency modulation in the synchronizing generator. As discussed in the preceding chapter, bowing of the line is indicative of 30 cycle modulation. Calibration of the oscillator is made by comparison with crystal controlled synchronizing signals.

The discussion of the preceding paragraph is applicable to those periods when the synchronizing generator is oscillating at a constant frequency. Normally, the syn-

chronizing generator output frequency will vary about the nominal 15,750 c.p.s., maintaining stable oscillation at any one frequency for only short intervals. The line A-B will appear to swing to the right and left with a speed dependent on the rate of change of the frequency. In addition, the lines A-C, D-E, etc. will no longer be straight lines, but will be slightly curved. The maximum tolerable curvature is illustrated in Figure 8. A kinescope recording of the monitor scope and subsequent analysis of the line curvature permits accurate determination of the rate of change of synchronizing pulse frequency over any desired number of lines. However, because of the time factor involved, this type of measurement is not practicable as an operating method.

Several limitations are involved in the use of this circuit as an operational measurement of the rate of change of horizontal synchronizing frequency. The device will indicate only tolerable or excessive df/dt of the synchronizing frequency as defined by the standards. The measurement can be made only over a period of 525 scanning lines, or 1/30 second. The assumption is made that the rate of change of frequency is approximately constant. This assumption is deemed valid on the basis of experimental evidence, and consideration of the smoothing action of the synchronizing generator lock-in circuit.

The line generated on the face of the monitor scope by the pulses from the stable keyed oscillator may be expressed

by the equation,

$$x = x_0 + f_0 t + \frac{1}{2} (df/dt) t^2$$

where, x = deviation from vertical reference line.

x_0 = initial deviation.

f_0 = initial frequency of synch pulses.

t = time

df/dt = rate of change of synch pulse frequency.

Assuming df/dt to be constant, it is seen that the path generated is a parabola. It is a simple matter to show that the second difference of a second degree equation is a constant. Hence, under conditions of uniform rate of change of synchronizing pulse frequency, point B of Figure 15 will move to the right or left a constant amount each successive frame. If df/dt is made equal to the maximum allowable rate of change of frequency, 23.6 cycles per second per second, it can be shown that this distance on a 10 inch monitor scope with 8 inch horizontal lines is equal to 0.2096 inches. In time this corresponds to 1.15 microseconds, assuming a line to take 55 microseconds.

The above discussion forms the basis for the rate of change of frequency measurement. The lines generated by the stable oscillator are made 0.2096 inches wide and blanked out except on the bottom two or three horizontal scanning lines of alternate fields. The presentation on the monitor scope is then a short black horizontal line at the bottom of the monitor picture which moves horizontally as the horizontal synchronizing frequency changes. So long as the

rate of change of frequency is within the tolerable limits, each successive line overlaps or meets the preceding one as it moves across the bottom of the picture. If the limit is exceeded a light space is left void between successive lines which can easily be noted by an observer. Thus an immediate indication is given that the limit of rate of change of horizontal synchronizing frequency is being exceeded, and remedial action can be taken.

The measurement of rate of change of horizontal synchronizing pulse frequency is made with S1 in position 2, Figure 13. V10 provides a fixed delay from the oscillator keying pulse, and V11 a gate pulse which enables the peaked pulses from the stable oscillator to trigger V9. The duration of the pulses from the one shot multivibrator, V9, is adjusted to 1.15 microseconds. These pulses are then clipped and mixed with the composite signal in V13 to be fed to the monitor scope. Calibration of the pulse length can be made by a simple measurement of the pulse length on the monitor screen.

It should be pointed out that the circuit of Figure 13 was not developed beyond the breadboard stage and many refinements are unquestionably possible. The circuit did however serve to verify the feasibility of the measurement methods last discussed. There is no question of the ability of the method to give accurate data on the instantaneous frequency of synchronizing signals, or of the presence of frequency modulation in the synchronizing signal. While the

measurement of the rate of change of horizontal synchronizing pulse frequency is not made within a period specified by the standards, the accuracy of the method seems adequate to meet operational needs.

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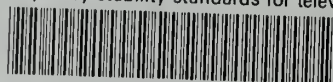
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